Modeling and Simulation of Voltage Source Model of UPFC in an IEEE 9 Bus System for Power Flow Enhancement

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***Abstract*— The Flexible Alternating Current Transmission (FACTS) devices such as UPFC are becoming important in suppressing power system oscillations and improving system damping. The UPFC is a solid-state device, which can be used to control the active and reactive power. This thesis considers a typical three-machine nine-bus system as a case study for investigating the performance of UPFC is achieving stability. By using a UPFC the oscillation introduced by the faults, the rotor angle and speed deviations can be damped out quickly than a system without a UPFC. The effectiveness of UPFC in suppressing power system oscillation is investigated by analyzing their oscillation in rotor angle and change in speed occurred in the three machine system considered in this work. A proportional integral (PI) controller has been employed for the UPFC. It is also shown that a UPFC can control independently the real and reactive power flow in a transmission line.**

A power system with UPFC is highly nonlinear. The most efficient control method for such a system is to use nonlinear control techniques to achieve system oscillation damping. The nonlinear control methods are independent of system operating conditions. Advanced nonlinear control techniques generally require a system being represented by purely differential equations whereas a power system is normally represented by a set of differential and algebraic equations.

A MATLAB simulation has been carried out to demonstrate the performance of the UPFC in achieving transient stability of the three-machine nine-bus system.

Keywords*— *FACTS, Real and Reactive Power Flow, IEEE 9 Bus System, IGBT, UPFC.

I. INTRODUCTION

The continuing rapid development of high-power semiconductor technology now makes it possible to control electrical power systems by means of power electronic devices. These devices constitute an emerging technology called FACTS (flexible alternating current transmission systems). Its first concept was introduced by N.G Hingorani, in 1988 (FACTS) is very popular and essential device in power systems [1]. FACTS technology has a number of benefits, such as greater power flow control, increased secure loading of existing transmission circuits, damping of power system oscillations, less environmental impact and, potentially, less cost than most alternative techniques of transmission system reinforcement.

In order to have a better use of the transmission capabilities of the transmission lines, different types of FACTS devices have been studied: Static VAR Compensator (SVC), Thyristor controlled series capacitor (TCSC),Static synchronous compensator (STATOM), Static series compensator (SSSC), Unified Power Flow Controllers (UPFCs), thyristor switched capacitor (TSC) thyristor controlled reactor (TCR) [2-10]. Several FACTS-devices have been introduced for various applications in power system.

The UPFC is the most versatile of the FACTS devices. It cannot only perform the functions of the static synchronous compensator (STATCOM), thyristor switched capacitor (TSC) thyristor controlled reactor (TCR), and the phase angle regulator but also provides additional flexibility by combining some of the functions of the above controllers. The main function of the UPFC is to control the flow of real and reactive power by injection of a voltage in series with the transmission line. Both the magnitude and the phase angle of the voltage can be varied independently. Real and reactive power flow control can allow for power flow in prescribed routes, loading of transmission lines closer to their thermal limits and can be utilized for improving transient and small signal stability of the power system.

This device combination of two other FACTS devices: the Static Synchronous Compensator (STATCOM) and the Static Synchronous Series Compensator (SSSC). Practically, these two devices are two Voltage Source Inverters (VSI's) connected respectively in shunt with the transmission line through a shunt transformer and in series with the transmission line through a series transformer. These are connected to each other by a common DC link, which is a typical storage capacitor [5-10].

II. UNIFIED POWER FLOW CONTROLLER

The UPFC is the most flexible multi-functional FACTs device which is a new generation of FACTS devices. The UPFC is one of the most versatile devices. In UPFC, the transmitted power can be controlled by changing three parameters of power transmission line namely transmission magnitude voltage, impedance and phase angle.

The UPFC consists of two voltage source converters; series and shunt converter, which are connected to each other with a common dc link. Shunt converter (converter 1) or Static Synchronous Compensator (STATCOM) is used to provide reactive power to the ac system, besides that, it will provide the dc power required for both inverters, while series converter (converter 2) or Static Synchronous Series Compensator (SSSC) is used to add controlled voltage magnitude line as shown in fig. 1. Each of the branches consists of a transformer and power electronic converter. These two voltage source converters shared a common dc capacitor. The real power can freely flow in either direction

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between the ac terminals of the two converters. In this respect, converter 2 provides the main function by injecting an AC voltage Vse, at system frequency with variable magnitude |Vse|, (|Vse| ≤ 0 ≤ |Vse| max) and phase angle (0 ≤ γ ≤ 2π) in series with the line. On the other hand, converter1 is used primarily to provide the real power demanded by converter2 at the common dc link [2].

The energy storing capacity of this dc capacitor is generally small. The reactive power in the shunt or series converter can be chosen independently, giving greater flexibility to the power flow control.

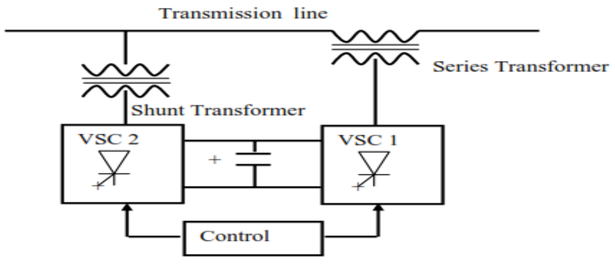

Fig.1. schematic diagram of the UPFC.

Fig.2 shows Single line diagram of UPFC and Phasor of voltage and current to V [7]. This gives a new line voltage V2 with different magnitude and phase shift.

As the angle φ varies, the phase shift δ between V2 and V3 also varies. Voltage and current with the presence of the two converters, UPFC not only can supply reactive power but also active power. The equation for the active and reactive power is given as follows,

$$P_{12} = \frac{V_1 V_2 \sin\delta}{X_{12}}$$

$$Q_{12} = \frac{V_1 V_2 (\cos\delta + 1)}{X_{12}}$$

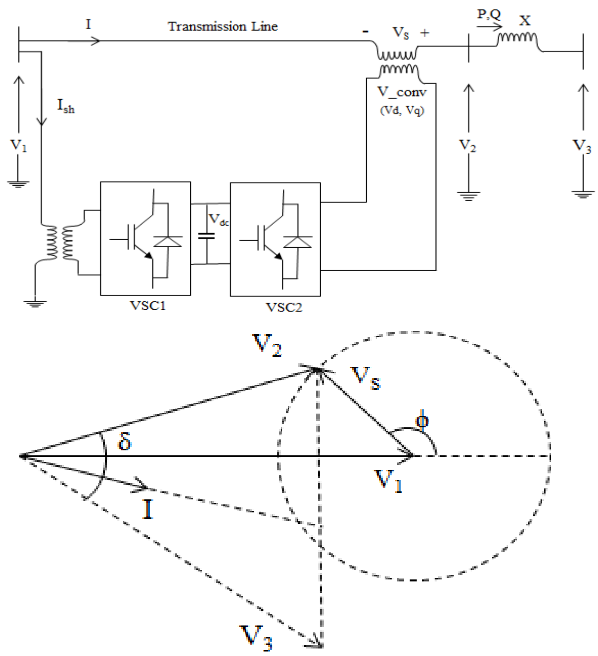

Fig.2. Single line diagram of UPFC and Phasor of Voltage and current.

III. VOLTAGE SOURCE CONVERTERS USED IN UPFC

A. *STATCOM*

A static synchronous generator operated as a shunt – connected static var compensator whose capacitive or inductive output current can be controlled independent of the ac system voltage. For the voltage-sourced converter, its ac output voltage is controlled such that it is just right for the required reactive current flow for any ac bus voltage dc capacitor voltage is automatically adjusted as require serving as a voltage source for the converter. STATCOM also designed to act as an active filter to absorb system harmonics. Fig-4 shows the schematic diagram of STATCOM without energy storage system.

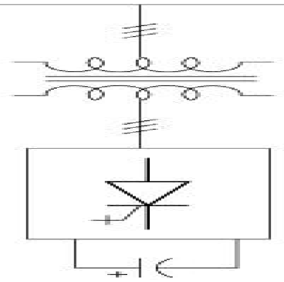

Fig.3. Schematic diagram of STATCOM without energy storage system.

B. *SSSC*

A Static synchronous series generator operated without an external electric energy source as a series compensator whose output voltage is in quadrature with and controlled independently of the line current for the purpose of increasing or decreasing overall reactive voltage drop across the line and thereby controlling the transmitted electric power. The SSSC may include transiently rated energy storage or energy absorbing devices to enhance the dynamic behavior of the power system by additional temporary real power compensation to increase or decrease momentarily the overall real voltage drop across the line.

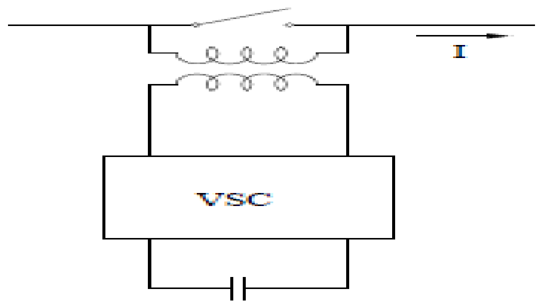

Fig.4. Schematic diagram of SSSC.

IV. CONTROL OF UPFC

As the UPFC consists of two converters that are coupled on the DC side, the control of each converter is explained below:

A. *Control of the Shunt Converter*

The block diagram of shunt converter is shown in fig 5.The shunt converter draws a controlled current from the system. One component of this current is Ip which is automatically determined by the requirement to balance the real power supplied to the series converter through the DC

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link. This power balance is enforced by regulating the DC capacitor voltage by feedback control.

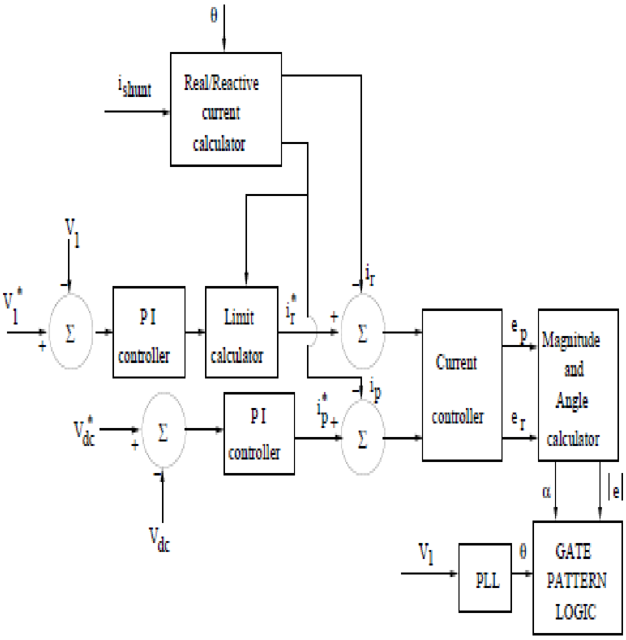

Fig.5. Block diagram of shunt controller.

The other component of the shunt converter current is the reactive current, Ir which can be controlled in a similar fashion as in a STATCOM. There are two operating (control) modes for a STATCOM or the shunt converter [17]. These are,

1. VAR control mode where the reactive current reference is determined by the inductive or capacitive VAR command. The feedback signals are obtained from current transformers (CT) typically located on the bushings of the coupling (step down) transformer.

2. Automatic voltage control mode where the reactive current reference is determined by the output of the feedback voltage controller which incorporates a droop characteristic (as in the case of a SVC or a STATCOM). The voltage feedback signals are obtained from potential transformers (PT) measuring the voltage V1 at the substation feeding the coupling transformer.

B. *Control of the Series Converter*

The block diagram of series converter is shown in fig.6. In this control mode, the series injected voltage is determined by a vector control system to ensure the flow of the desired current (phasor) which is maintained even during system disturbances (unless the system control dictates the modulation of the power and reactive power).

Although the normal conditions dictate the regulation of the complex power flow in the line, the contingency conditions require the controller to contribute to system stability by damping power oscillations.

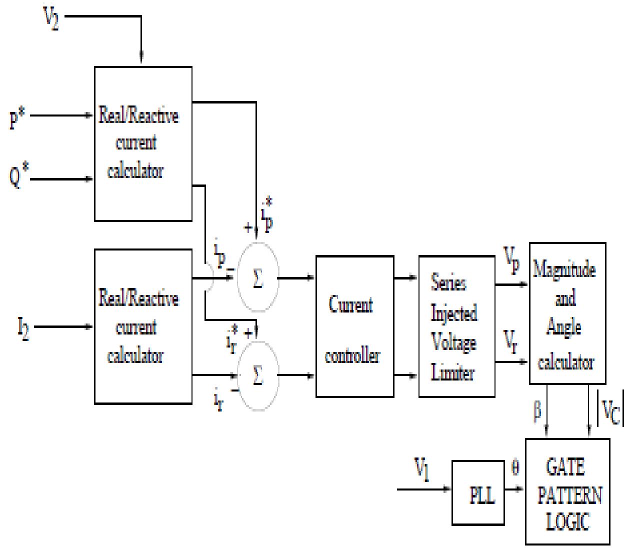

Fig.6. Block diagram of series controller.

The different control modes for the series voltage are given:

1. Direct voltage injection mode where the converter simply generates a voltage phasor in response to the reference input. A special case is when the desired voltage is a reactive voltage in quadrature with the line current.

2. Phase Angle Shifter Emulation mode where the injected voltage is phase shifted relative to the voltage by an angle specified by the reference input.

3. Line impedance emulation mode where the series injected voltage is controlled in proportion to the line current.

4. Automatic power flow control mode where the reference inputs determine the required real power (P) and the reactive power (Q) at a specified location in the line.

V. SIMULINK MODEL

In this section, Controlling and Simulation of UPFC has been discussed using MATLAB environment. For Multi Machine (3 machines 9 bus) system simulation work has been carried out. By considering the occurrence of three phase fault and varying different system parameter has been analyzed for varies responses in this case. With the damping constant, Fault clearing time and the location of fault and its effect on the system stability leads to learning about variation of load angle has been carried out during investigation.

The IEEE System having 3-machines 9-bus with standard value of parameters has been considered as a test case. The MATLAB/Simulink based model of IEEE 3-Machine 9-Bus system without UPFC shown in Fig.7. In this model compensating device is not connected. It provides transient response of system in the condition of with fault.

In MATLAB/Simulink based model of IEEE 3-Machine 9-Bus system with UPFC and different types of phase fault in between bus 5-7 are shown in Fig. 8.

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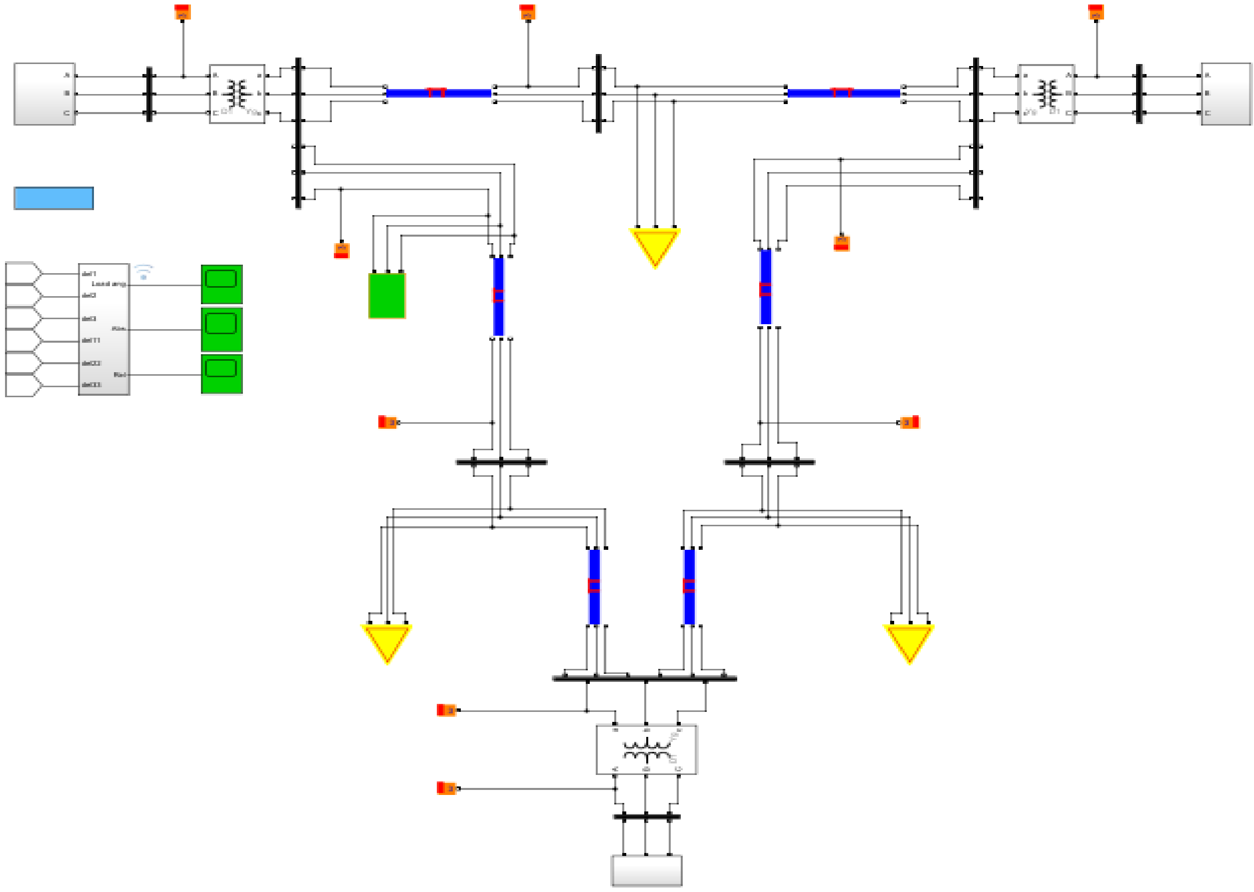

Fig. 7. MATLAB/Simulink Based Model of IEEE 9bus system without UPFC.

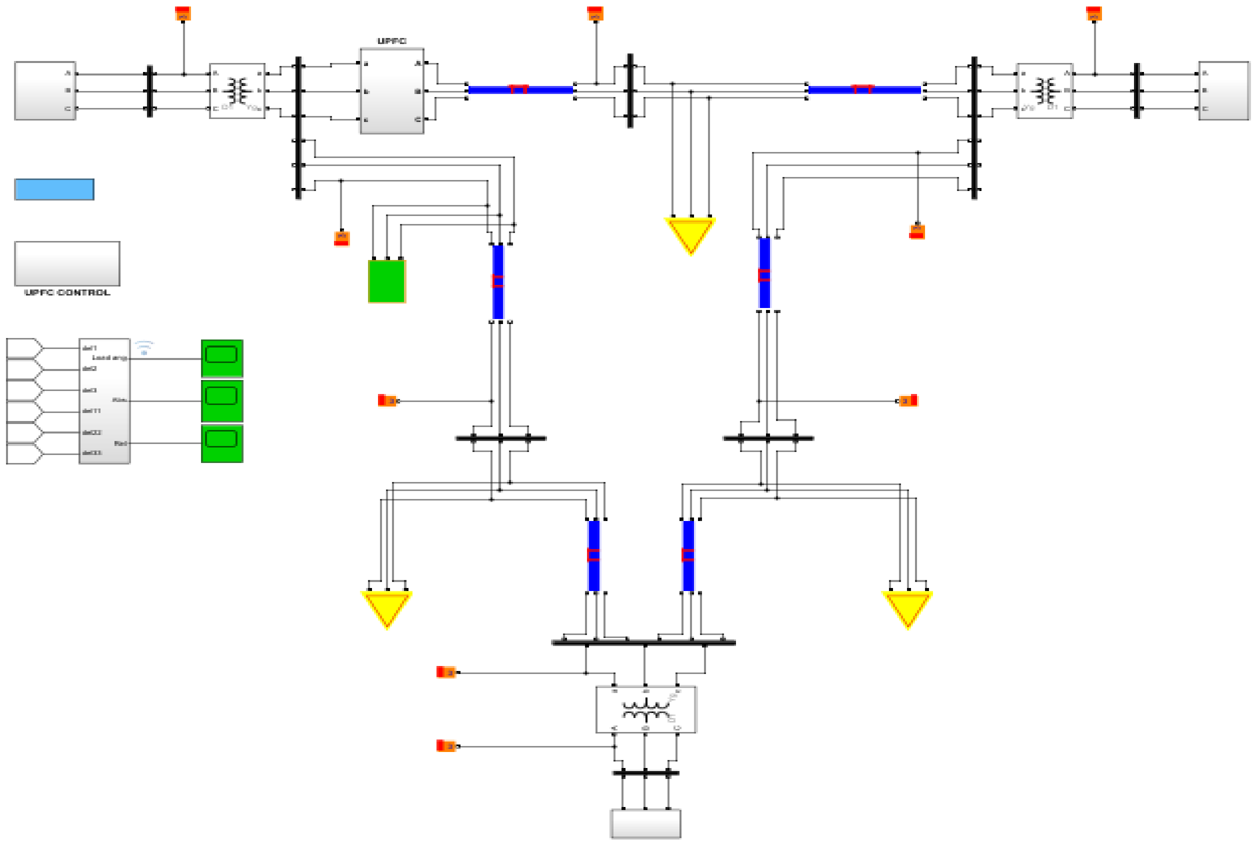

Fig. 8. MATLAB/Simulink Based Model of IEEE 9bus system without UPFC.

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The UPFC simulink module is shown in Fig.9. In converter controller different type of blocks are used like Phase Locked Loop (PLL), measurement, current regulator and reference computation block. To match the frequency of an input signal voltage driven oscillator that repeatedly adjusted by the PLL block. The value of P, Q, Vd, Vq, Id, and Iq are measure by measurement system with the help of bus terminal frequency and voltage. Measurement of Id and Iq reference values done by reference computation block with the help of reference values of P, Q and Vd, Vq. The Vd, Vq value and the current value are generated by current regulator block between both converters and generate sigma signal voltage is compared with DC voltage transferred in Sigma Computation block. To control the operation of converters firing pulse generator produces firing pulse on basis of reference values as shown in Fig.10.

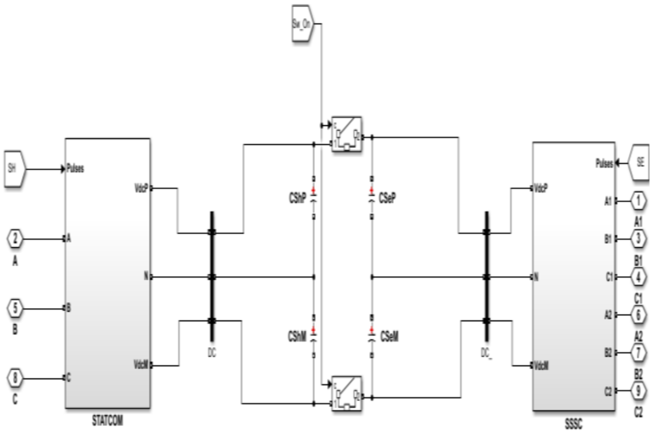

Fig. 9. MATLAB/Simulink Based Model of UPFC.

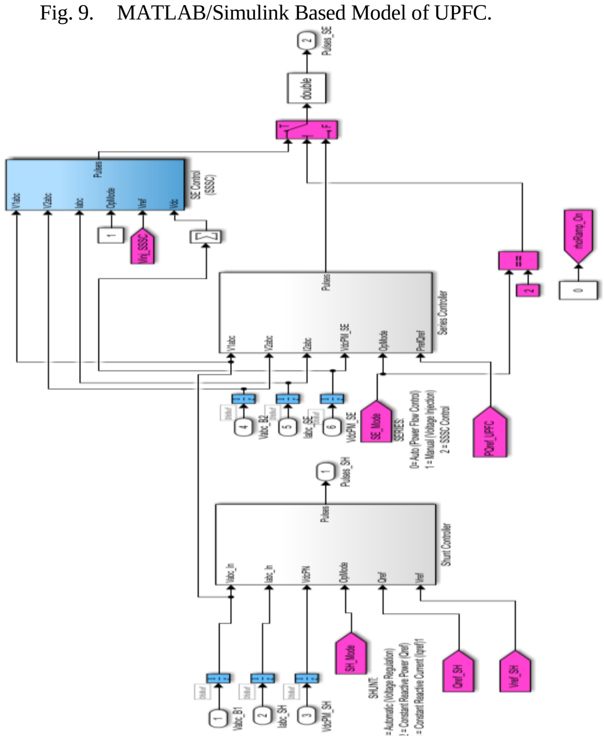

Fig. 10. MATLAB/Simulink Based Model of UPFC Control.

VI. SIMULATION RESULT

A fault was considered in between 5-7 and their effect was studied with and without UPFC. The three phase fault is occurring just after 1 second and fault clearing time is 1.08 second. The variation of load angle 1, 2, 3 with respect to time is observed.

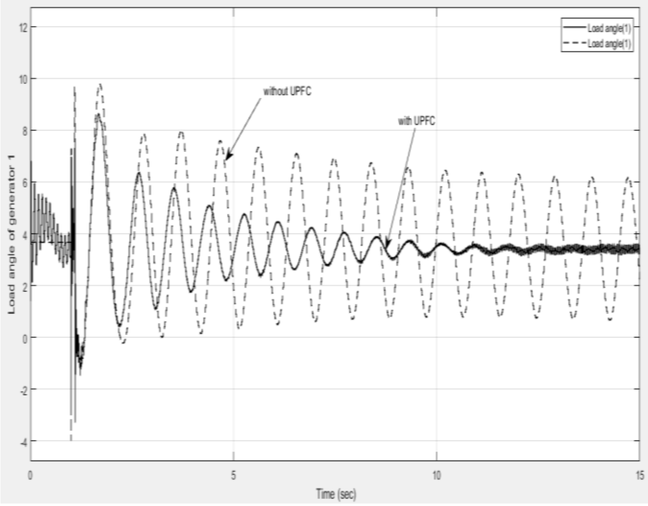

Fig. 11. Rotor angle of G1 with and without UPFC.

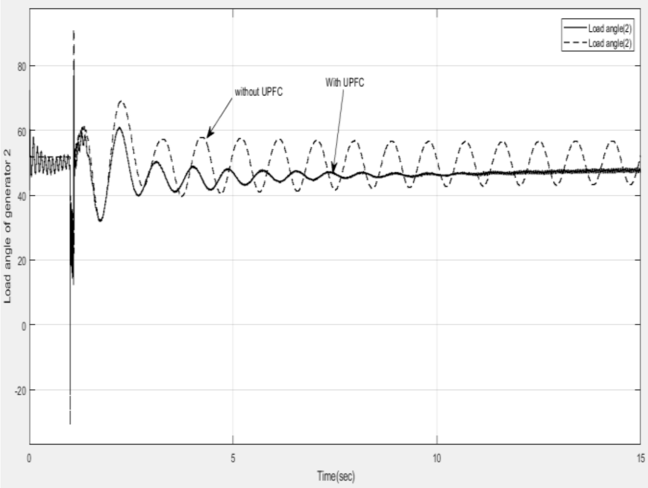

Fig. 12. Rotor angle of G2 with and without UPFC.

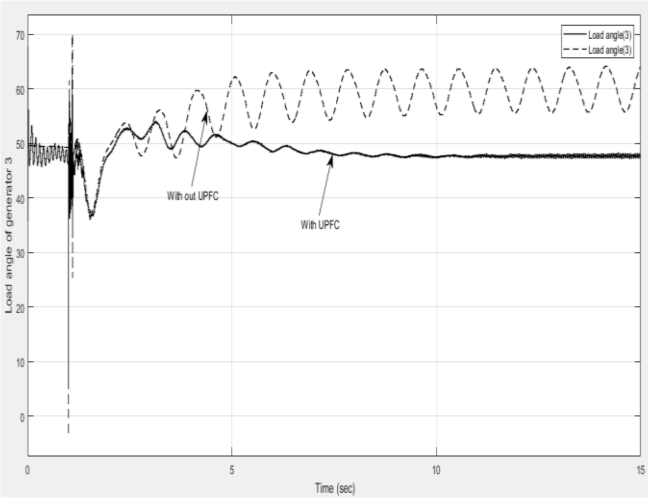

Fig. 13. Rotor angle of G3 with and without UPFC.

VII. CONCLUSION

From the proposed technique of adding the UPFC in the transmission line of the power system, gets the better results as compared to the older techniques power system stabilizer and automatic voltage controller in terms of damping out the transients quickly. We have carried out extensive computer simulations for studying the addition of both series compensation and shunt compensation given by the series controller and the shunt controller. From comparative study of the relative variation in rotor angle and relative change in speed of the three machines nine-bus system with the proposed technique and conventional technique, we have seen that the transient stability is enhanced by the use of UPFC. By using a UPFC we obtain better transient stability performance than the case without a UPFC.

Here we highlight some of the paper contributions as follows. It describes the role of UPFC on stability improvement of power system. This paper demonstrates the advantages of using UPFC by presenting a number simulation results.

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